Arapuca Photon Detector Response to Beam Electrons

Dante Totani, UCSB

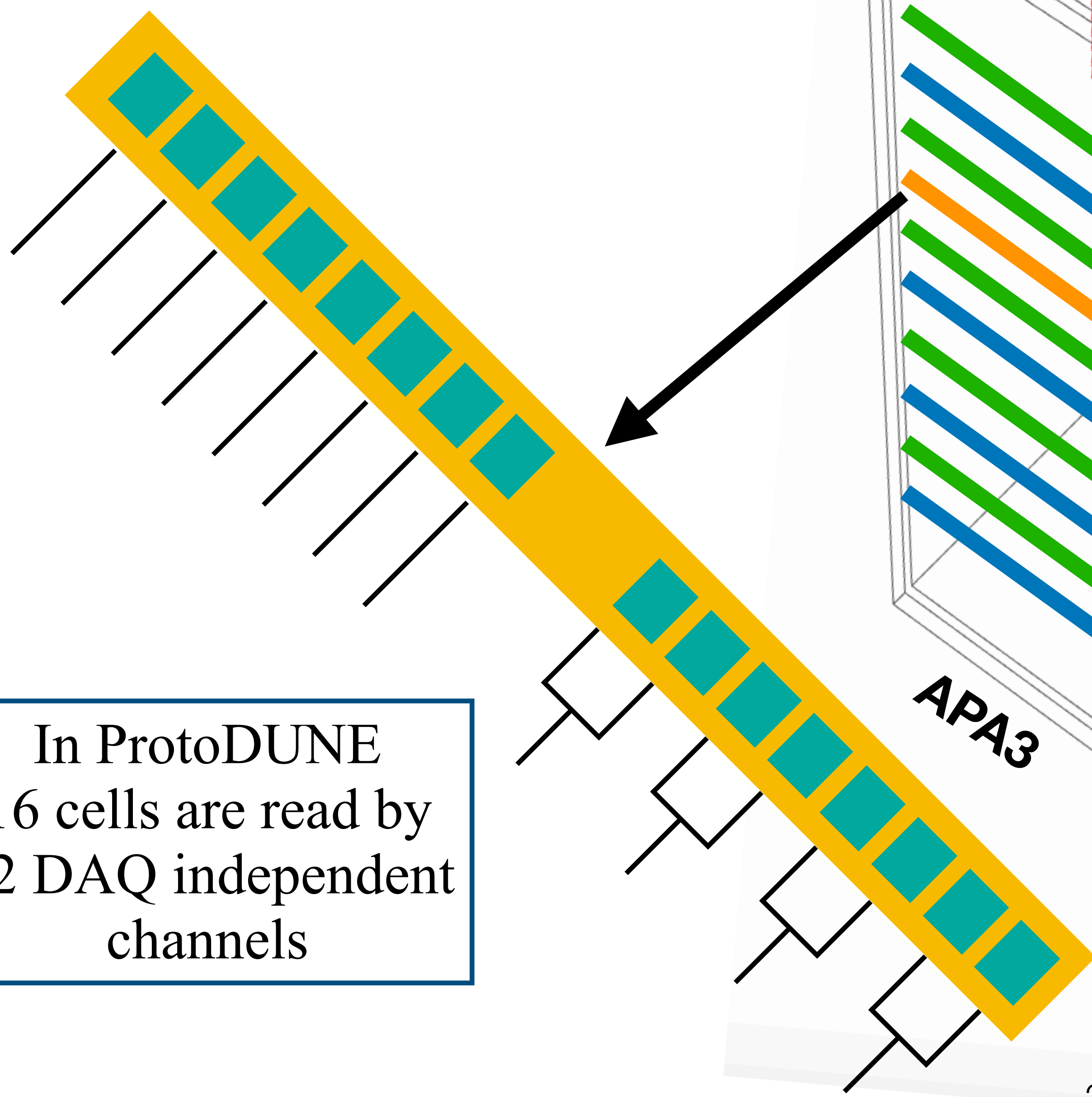
March 22nd, 2021

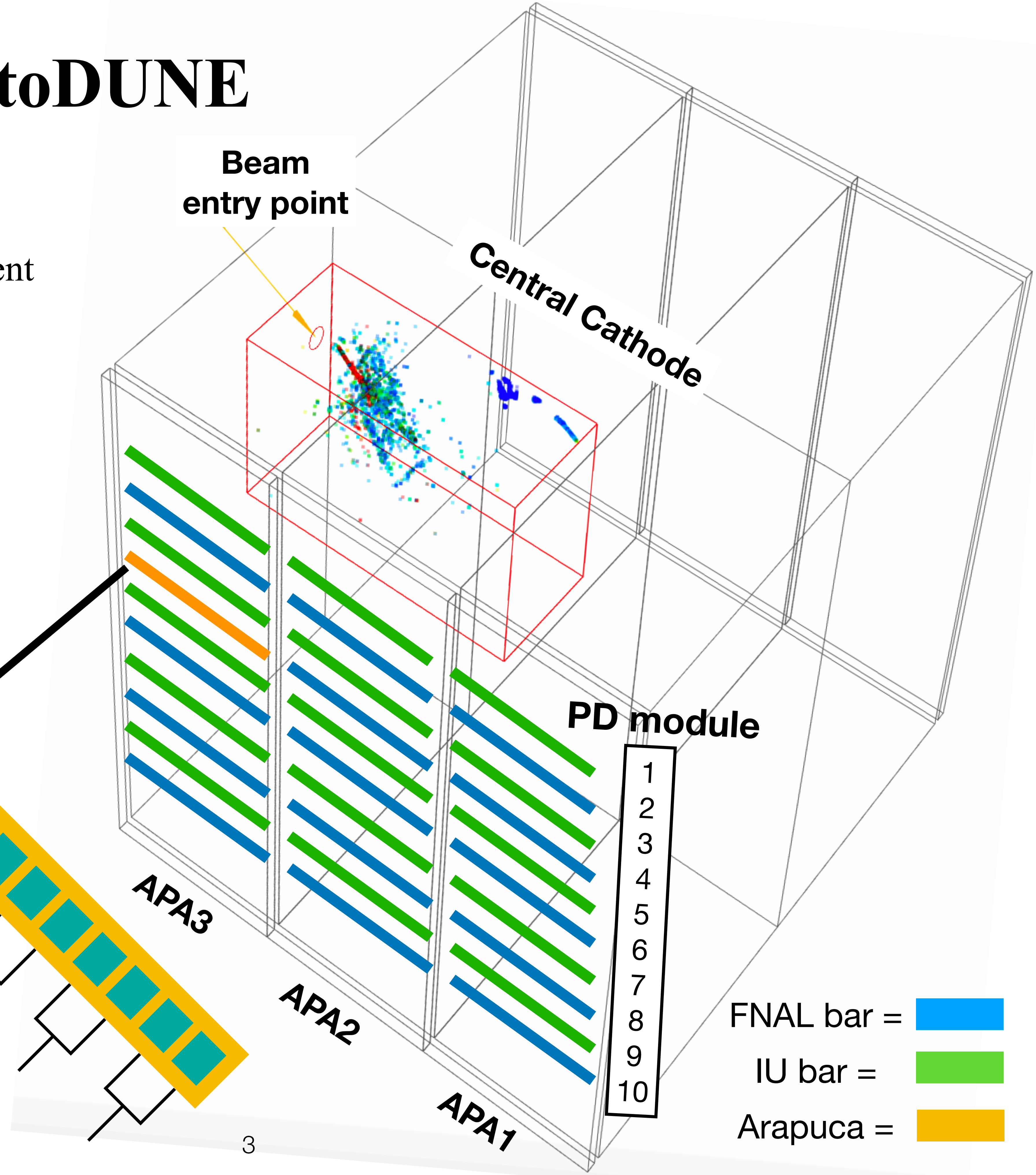
Summary

- ARAPUCA in ProtoDUNE
- Particle identification
- Outlier removal
- Arapuca spectra
- Gaussian fit and parameters error
- Spectrometer resolution and beam momentum degradation
- Linearity and Resolution

Arapuca in ProtoDUNE

One Arapuca module is
composed by 16 independent
cells 8x10cm^2





In ProtoDUNE
16 cells are read by
12 DAQ independent
channels

Particles identification

- Electrons are classified using the Low Pressure (LP) Cherenkov detector.

Cherenkov detector

6, 7 Gev/c	HP	LP	3 GeV/c	HP	LP	2, 1, 0.5, 0.3 GeV/c	LP
Electron / Pion	1	1	Electron	1	1	Electron	1
Kaon	1	0	Pion	1	0	Pion	0
Proton	0	0	Proton	0	0	Proton	0

LP (HP)= Low (Hi)

- Signature given by Pandora reconstruction solves the e/π ambiguity at higher energy (6 and 7 GeV).

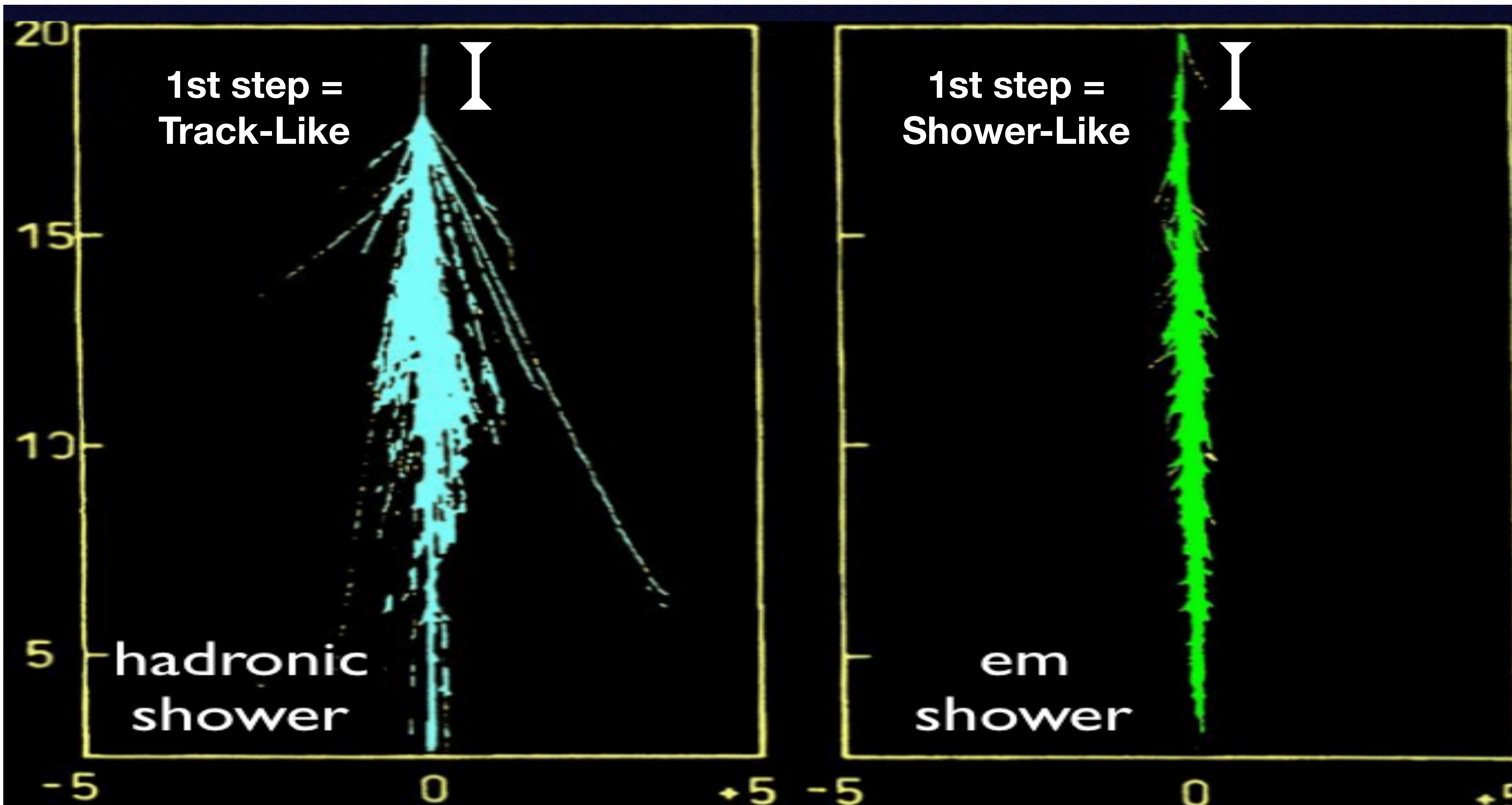
Pandora signature of first event's step:

Shower-Like $\rightarrow e$

Track-Like $\rightarrow \pi$

Example of e/π showers.

Entering the TPC, Electrons produce immediately the shower while Pions travel as a MIP before producing the shower.



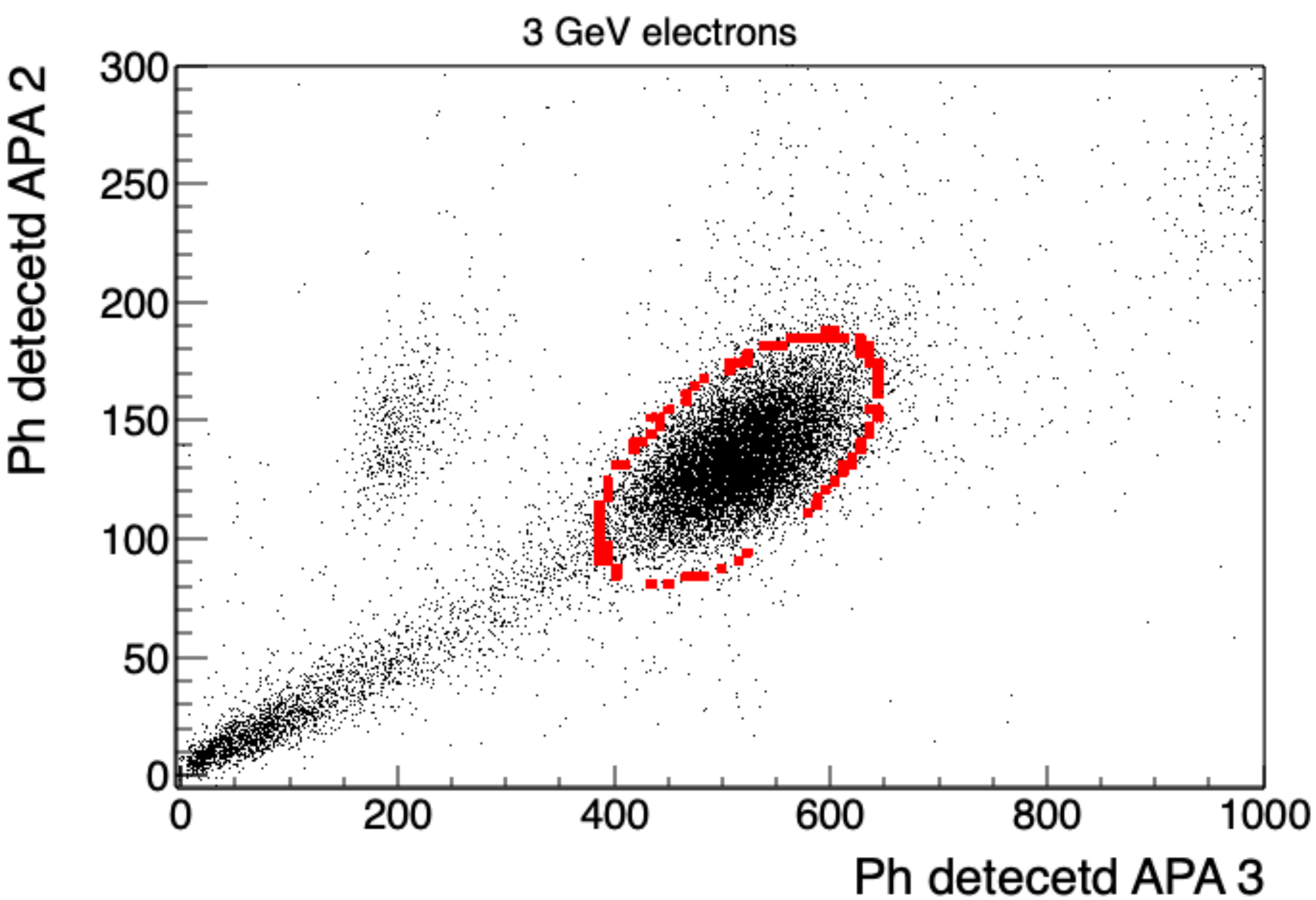
Outlier removal: spectra analysis

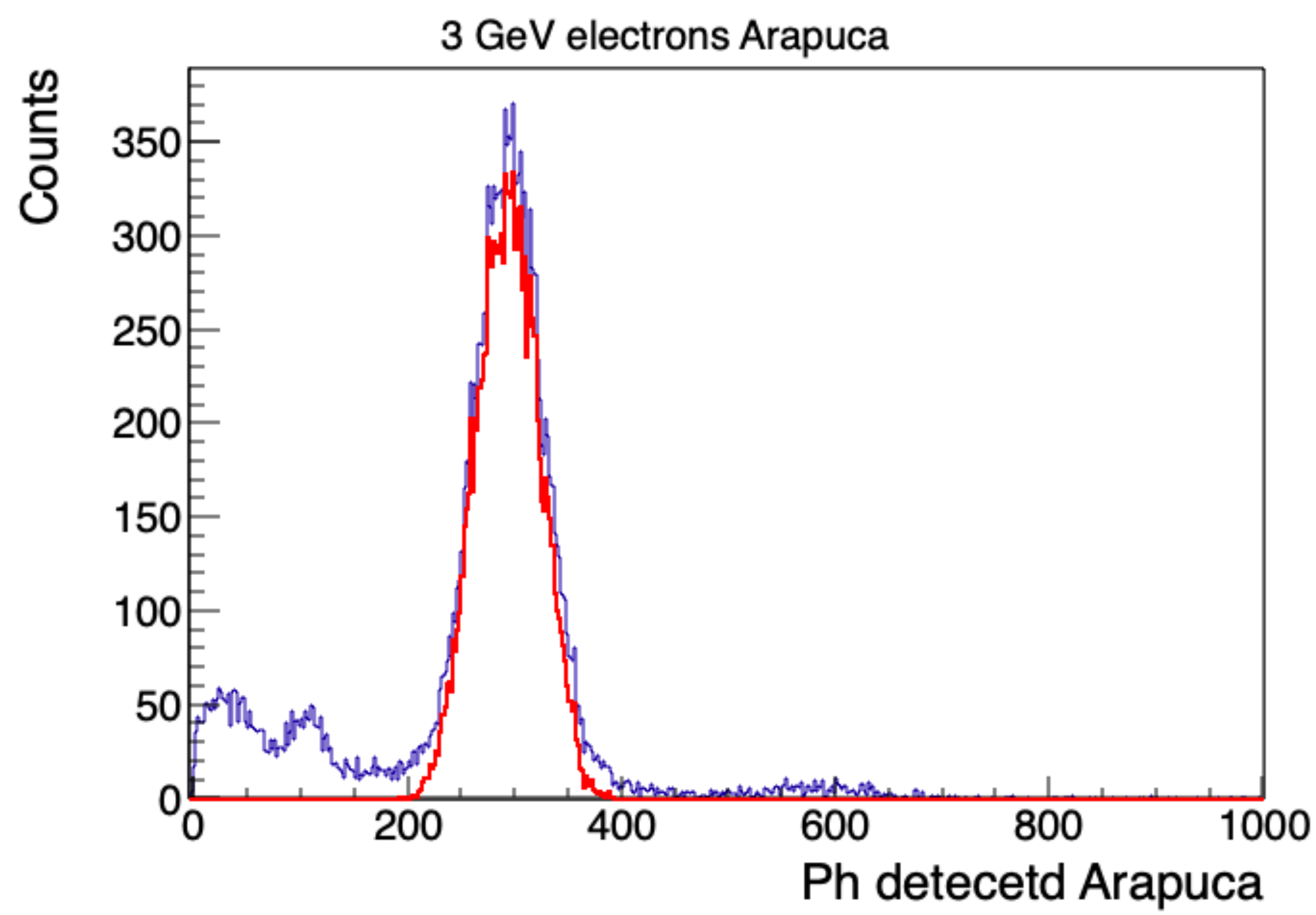
Scatter plots between the total number of photons collected from the entire APAs helps to remove extraneous events, which affect the average of photon detected.

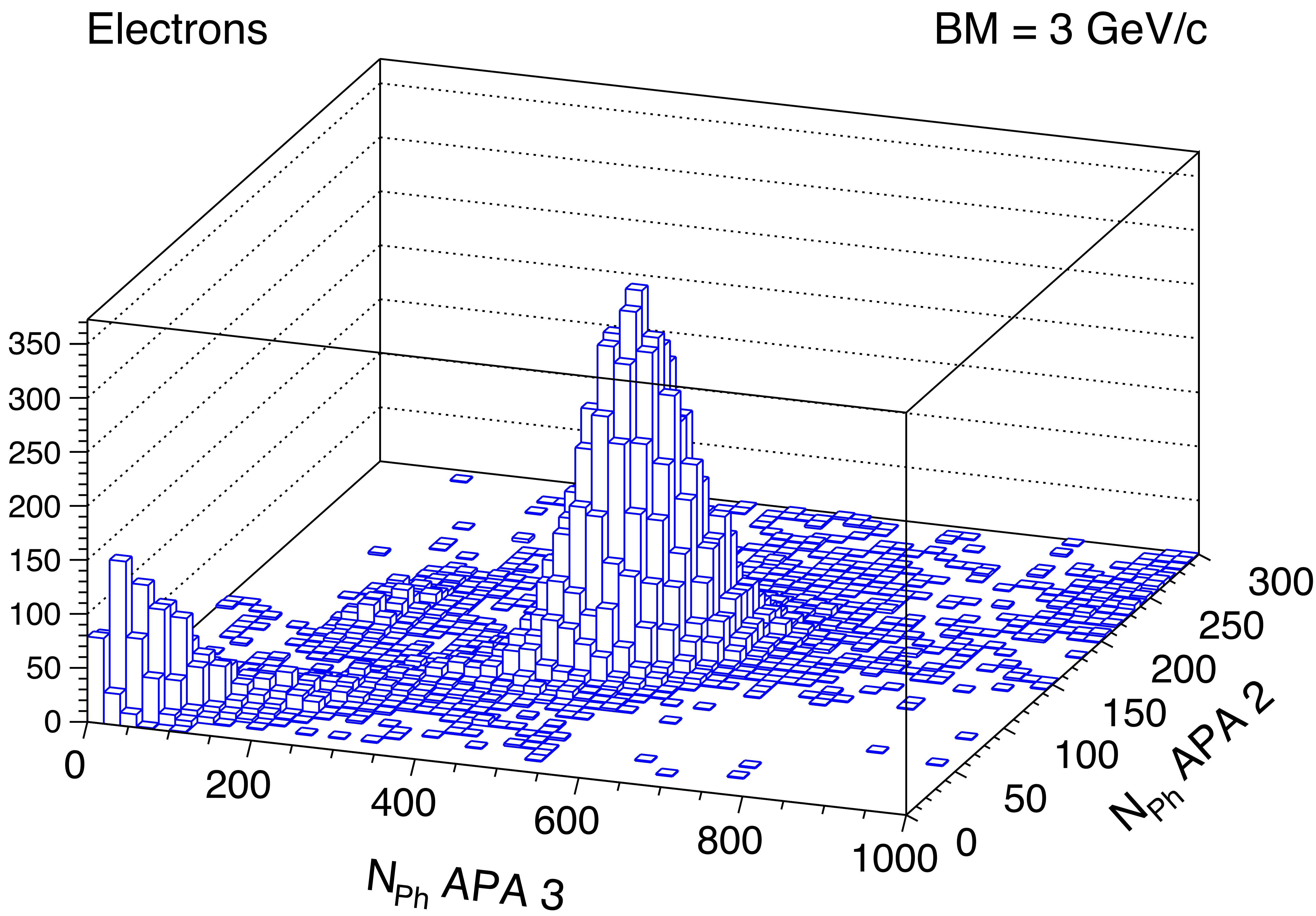
The peak is fitted with a rotated 2d gaussian function.
The cut is an ellipse with diameters equal to 6 sigma.

$$\begin{bmatrix} \sigma_x^2 & \rho\sigma_x\sigma_y \\ \rho\sigma_x\sigma_y & \sigma_y^2 \end{bmatrix} \rightarrow \begin{bmatrix} \sigma_\chi^2 & 0 \\ 0 & \sigma_\eta^2 \end{bmatrix}$$

On the left plot are reported the spectra for 3 GeV electrons before and after the cut



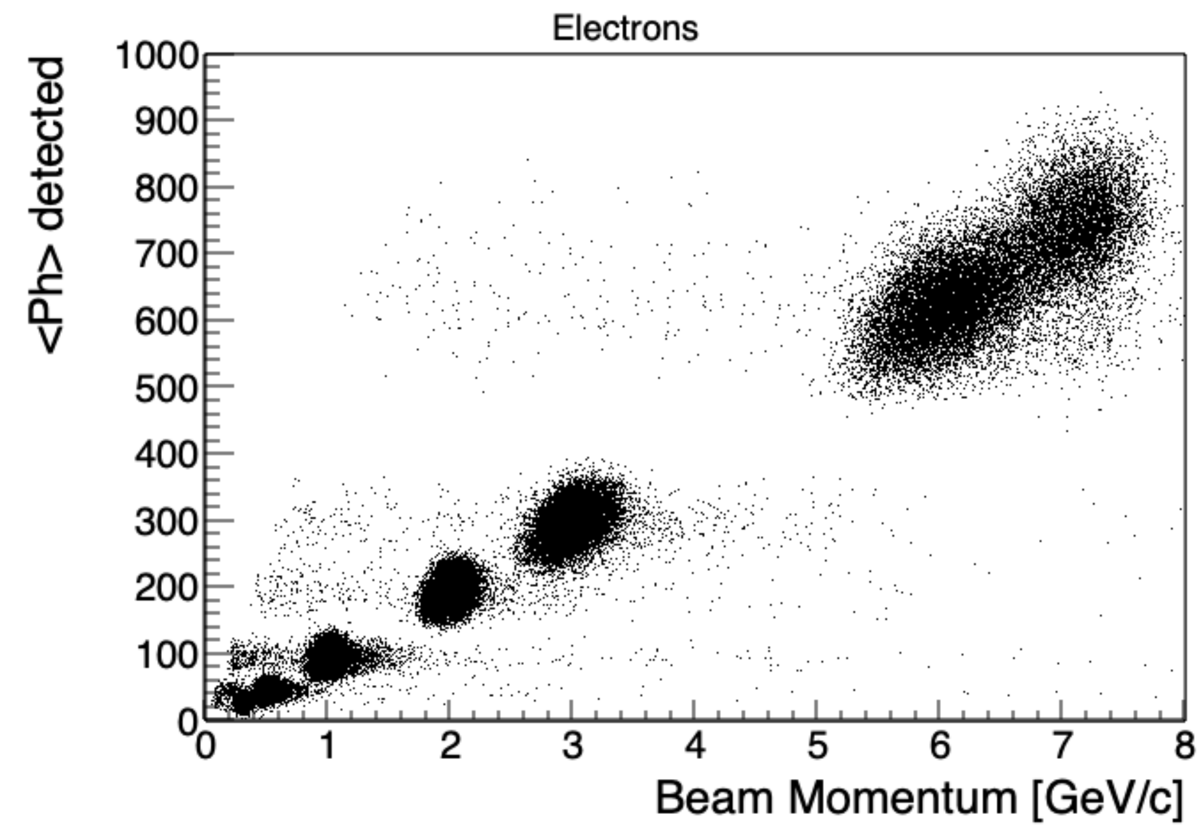




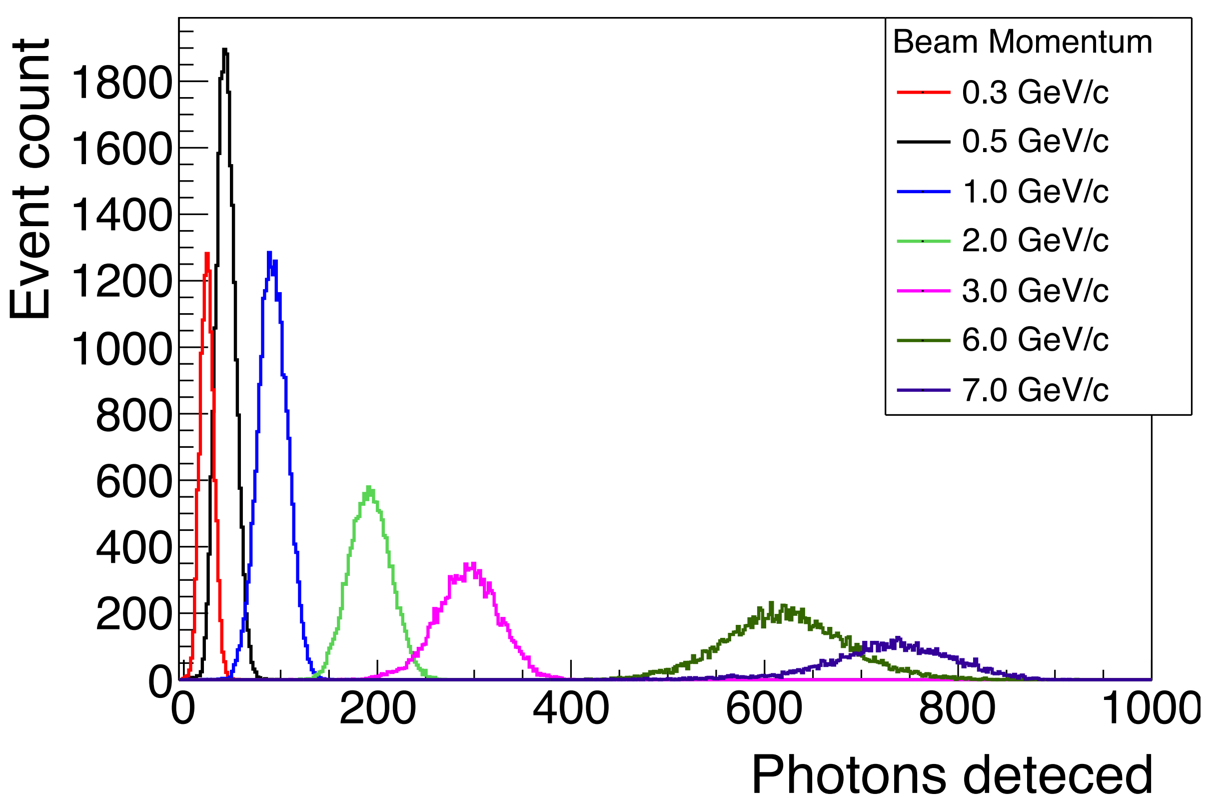
Electrons
BM = 3 GeV/c
0
50
100
150
200
250
300
350
0
200
400
600
800
1000
N_{Ph} APA 3
0
50
100
150
200
250
300
N_{Ph} APA 2

Arapuca response to beam electrons

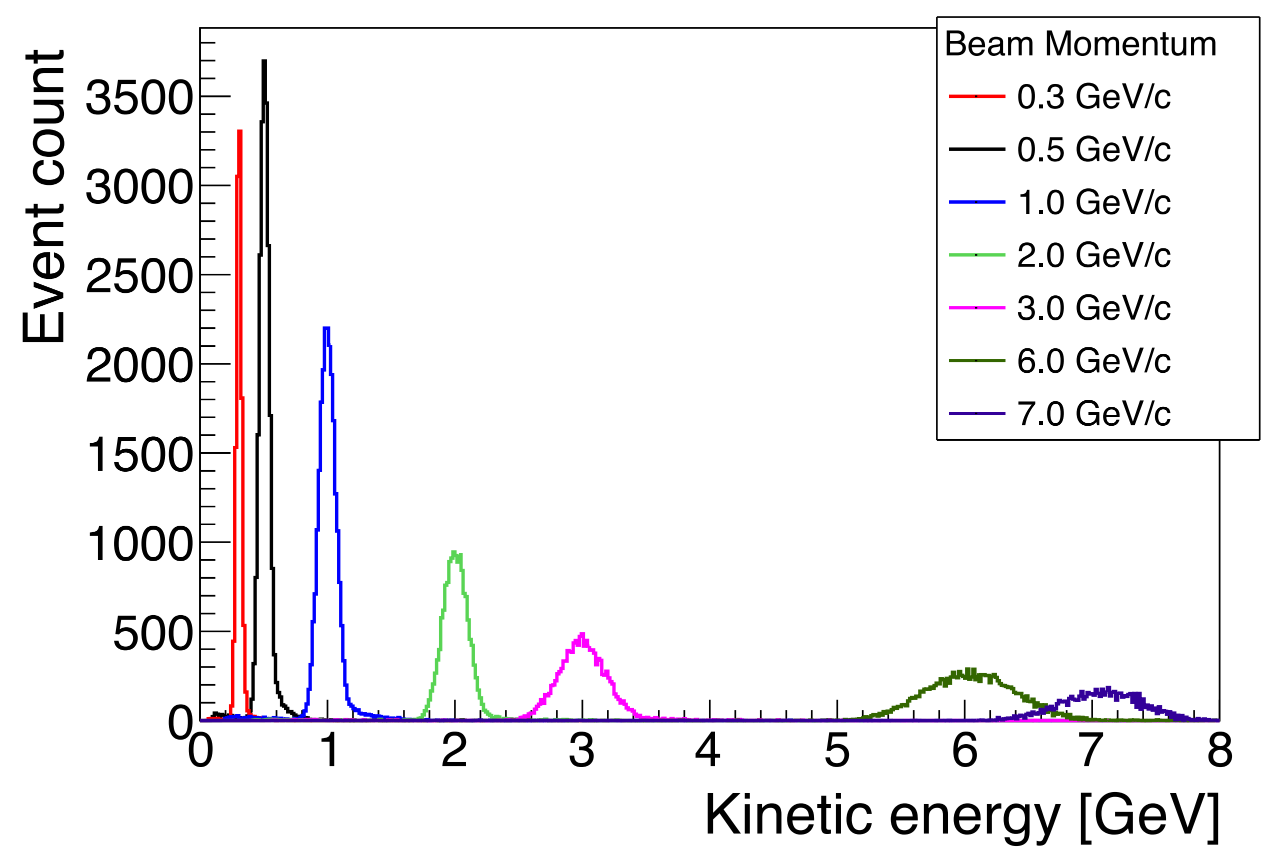
For each beam momentum nominal value Photons detected spectra and kinetic energy spectra are fitted with gaussian distributions. Two quantities are then analyzed: linear response and resolution.



Ph detected

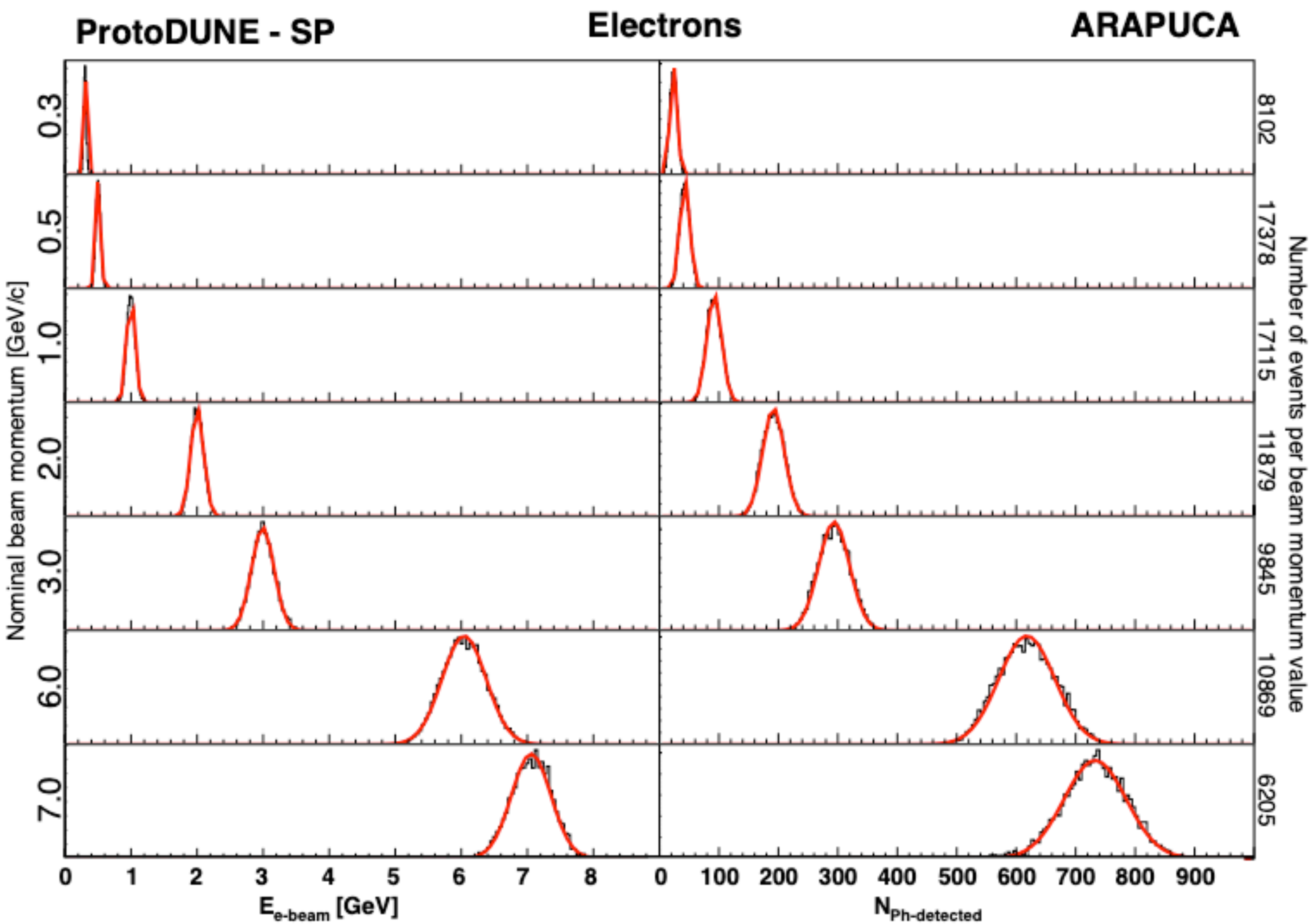


Kinetic energy



Gaussian fit

- The Gaussian fit gives two quantities with the error associated: $\mu \pm \Delta\mu$ and $\sigma \pm \Delta\sigma$.
- The error on the mean value form the fit "$\Delta\mu$" is similar to the one expected $\sigma/\sqrt{N}$.



Consideration on errors

$\langle N_{Ph} \rangle$ vs. E_{beam} $\qquad\qquad$ $\sigma_{Ph}/\langle N_{Ph} \rangle$ vs. E_{beam}

Both linear and resolution plots have no horizontal error.
E_{beam} uncertainty is included in the vertical error bars:

$$\Delta\langle N_{Ph}\rangle = \langle N_{Ph}\rangle \sqrt{\left(\frac{\Delta\langle\mu_{N_{Ph}}\rangle}{\langle\mu_{N_{Ph}}\rangle}\right)^2 + \left(\frac{\Delta\mu_{E_{beam}}}{\mu_{E_{beam}}}\right)^2}$$

$$\Delta\left(\frac{\sigma_{Ph}}{\langle N_{Ph}\rangle}\right) = \frac{\sigma_{Ph}}{\langle N_{Ph}\rangle} \sqrt{\left(\frac{\Delta\langle\sigma_{N_{Ph}}\rangle}{\langle\sigma_{N_{Ph}}\rangle}\right)^2 + \left(\frac{\Delta\langle\mu_{N_{Ph}}\rangle}{\langle\mu_{N_{Ph}}\rangle}\right)^2 + \left(\frac{\Delta\mu_{E_{beam}}}{\mu_{E_{beam}}}\right)^2}$$

The errors so defined result to be very small giving a huge χ^2 in the fit.
Moreover a correlation between the two variables (not take into account in that analysis) should reduce further the errors.

In the other hand, the beam energy measurement has an intrinsic error due to the momentum spectrometer resolution and there is a energy degradation between the last spectrometer and the particle ionizing region in the TPC.

Momentum spectrometer resolution and energy degradation

The paper takes into account is referred to a simulation for the Dual Phase beam line, but results should be applicable for the Single Phase beam line too.

CERN-ACC-NOTE-2016-0052

2016-07-28

Beam performance and instrumentation studies for the ProtoDUNE-DP experiment of CENF

N. Charitonidis[*, 1], Y.Karyotakis[2, 1] and I. Efthymiopoulos[1]

[1] CERN, 1211 Geneva 23, Switzerland
[2] LAPP, Lab. d'Annecy-le-Vieux de Physique de Particules, 74941 Annecy-le-Vieux CEDEX - France

Simulation **Momentum spectrometer resolution**

Figure 23: Momentum resolution of the spectrometer for three different position resolutions, namely 0.2, 0.5 and 0.8 mm

The majority of the beam runs should be acquired using a spectrometer "opening" = 0.5 mm, except for first 7 Gev runs when the spectrometer opening was still not fixed. (Not sure about that, however in the analysis the 5mm case is used).

Simulation

Momentum degradation

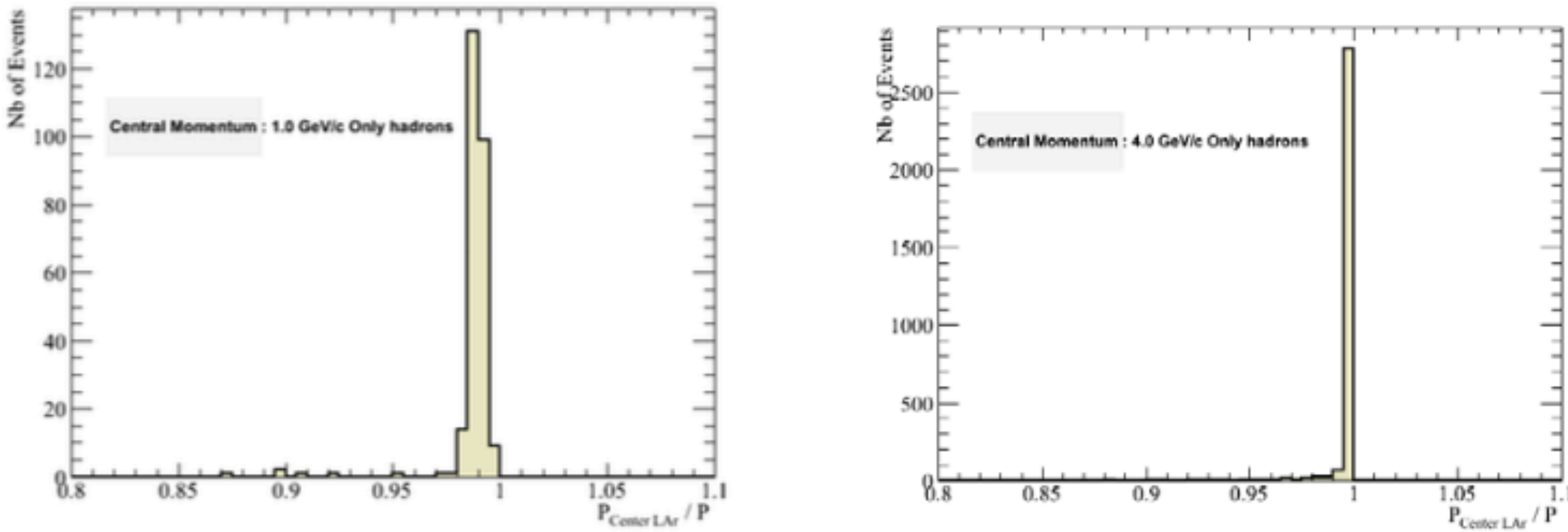
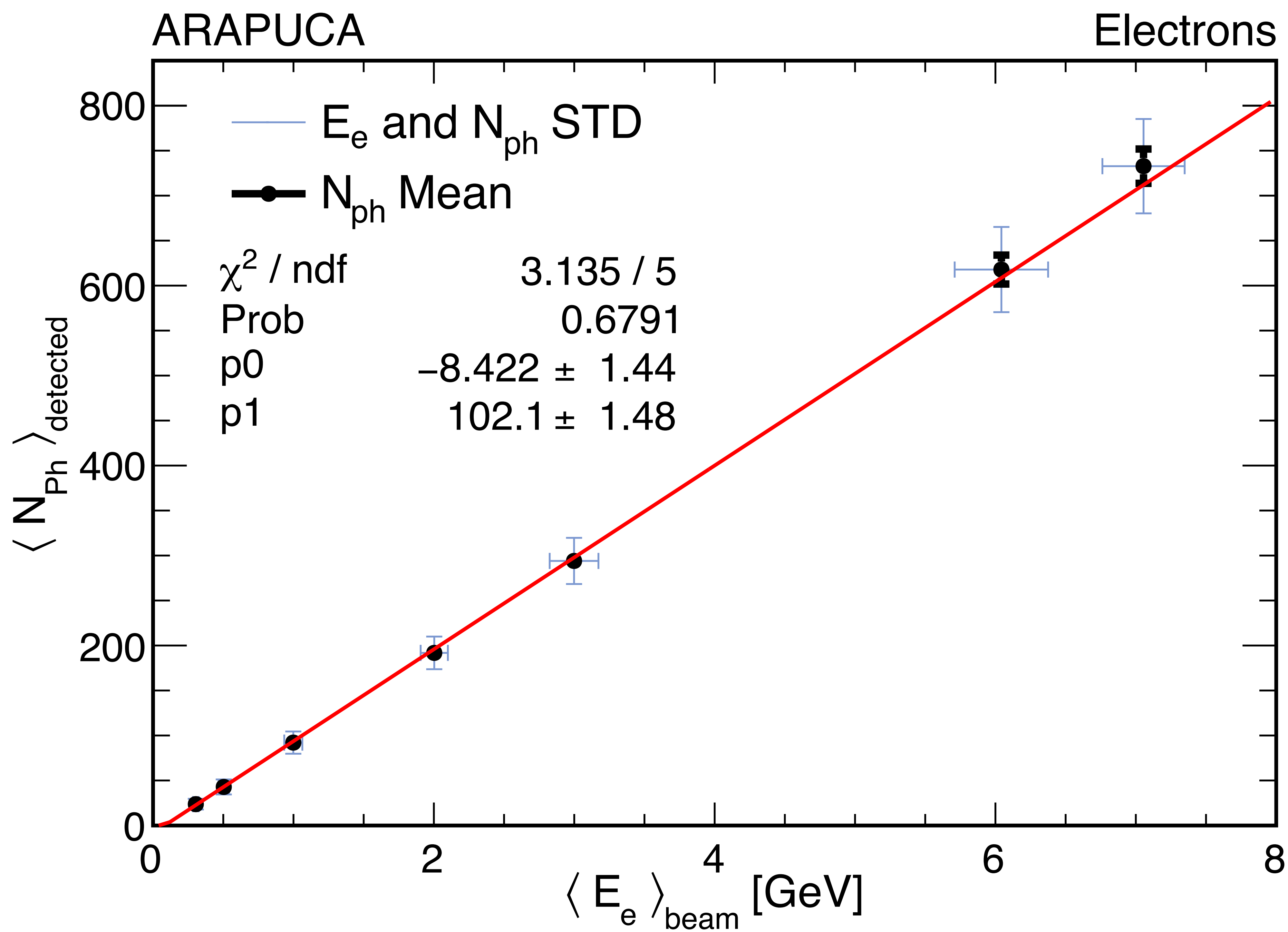


Figure 24: Deterioration of particles' momenta due to the material present in the line, for the case of 1 and 4 GeV. The effect is more pronounced in the lower energies.

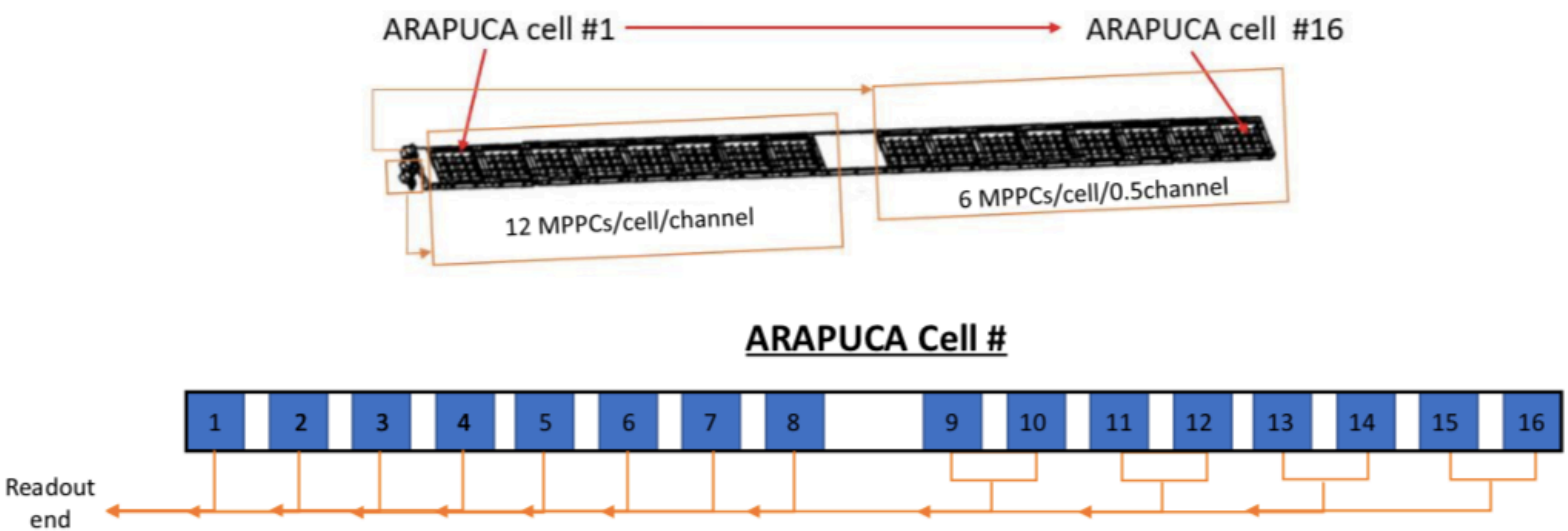
The energy deterioration was not full reported in the paper. However comparing the two plot shown for 1 GeV and 4 GeV the hypothesis of an energy independent loss seems right. Probably the value from simulation seems to underestimate the one found in the measurements from both Light and Charge (remember that the simulation is for the Dual Phase TPC).

Linearity


ARAPUCA
Electrons
E_e and N_{ph} STD
N_{ph} Mean
χ^2 / ndf 3.135 / 5
Prob 0.6791
p0 −8.422 ± 1.44
p1 102.1 ± 1.48
$\langle N_{Ph} \rangle_{detected}$
$\langle E_e \rangle_{beam}$ [GeV]
0
200
400
600
800
0
2
4
6
8

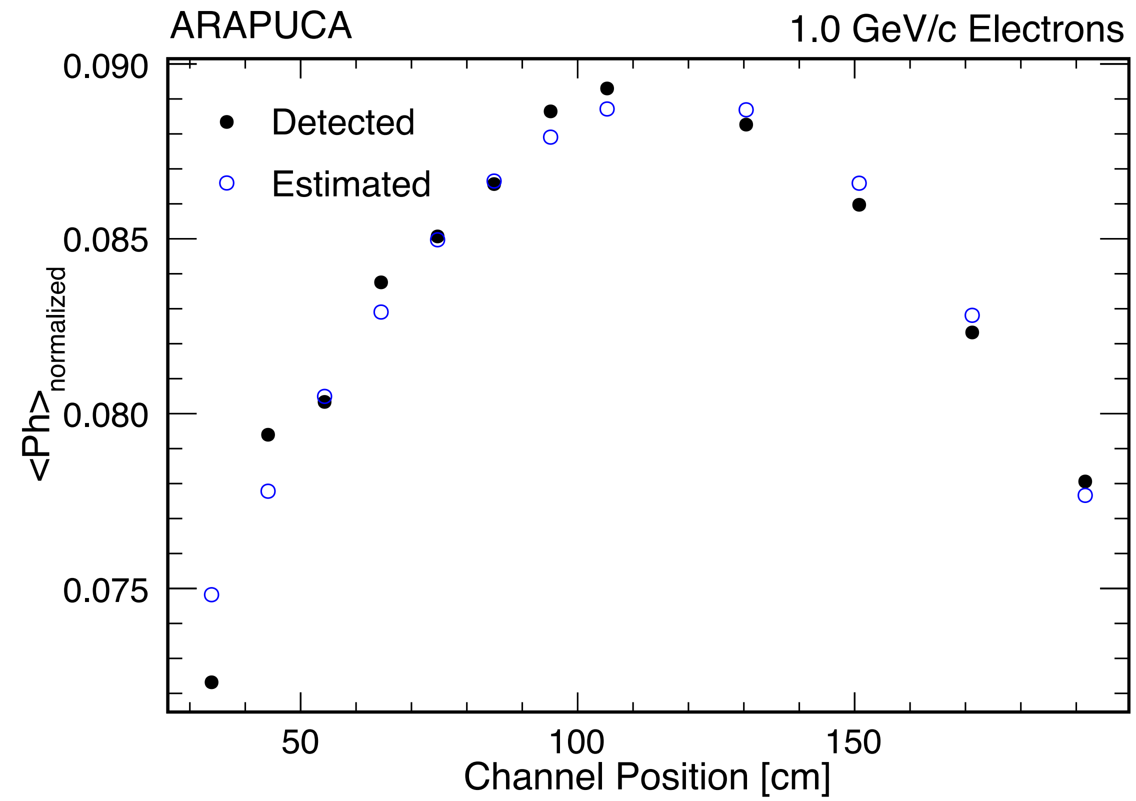
The Arapuca detector granularity

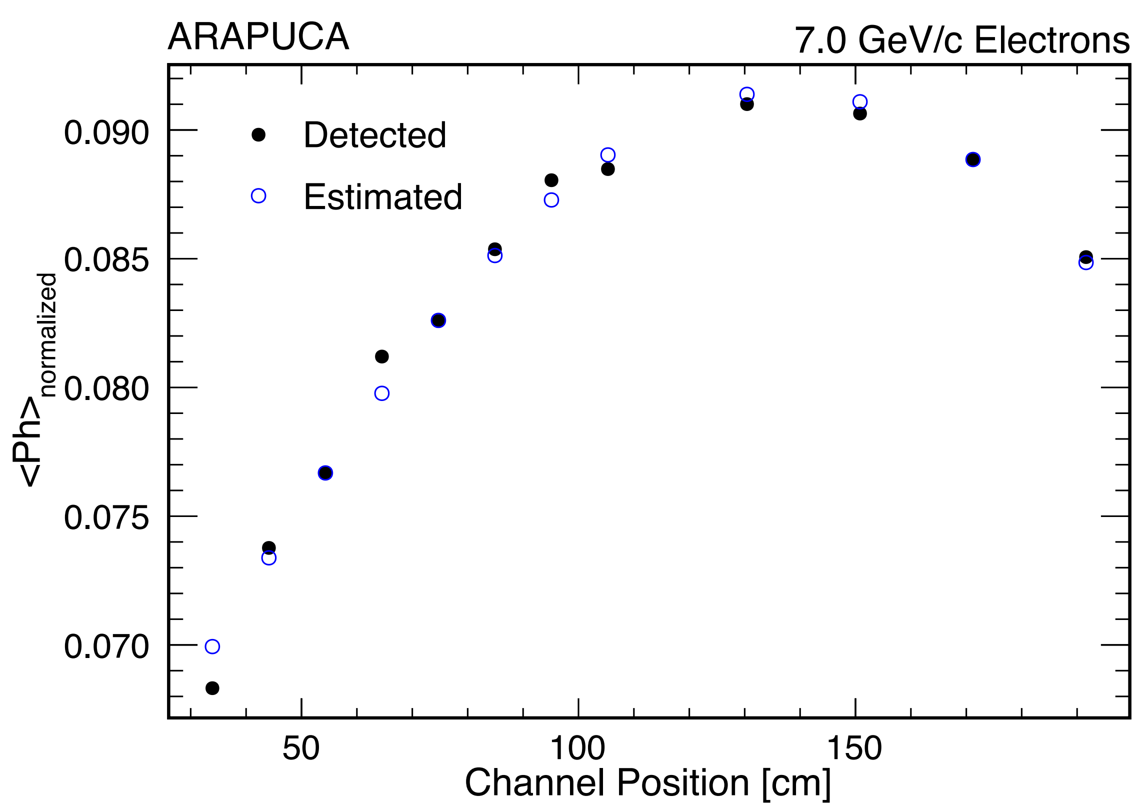
Until now we have looked at the Arapuca as a unique detector, but it is segmented and each cell can be read by an independent channel.

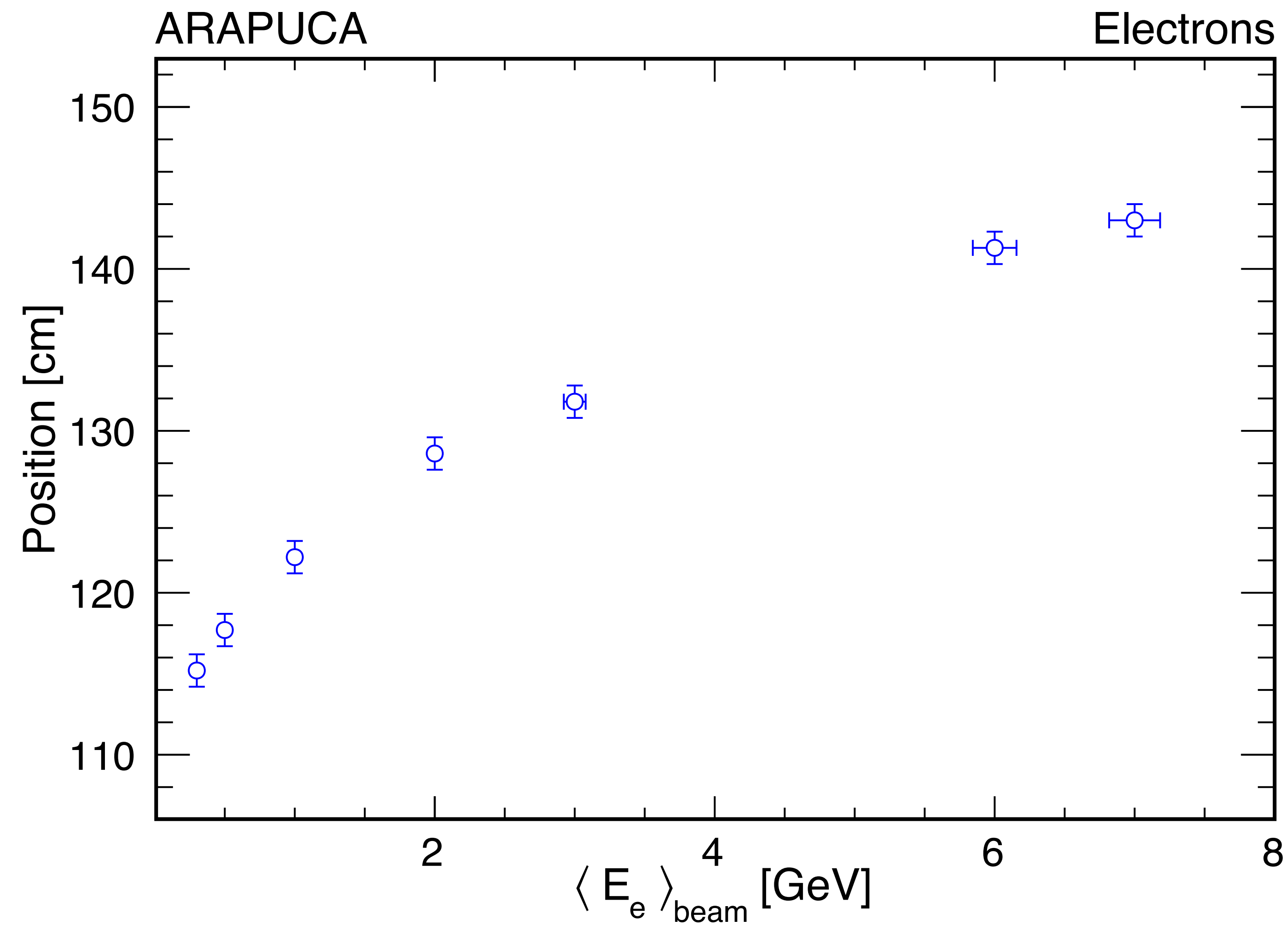


In protoDUNE the 2 Arapuca installed consist in 16 cells 8 read by a single channel and 8 read in couples

Geometrical corrections to normalize shower solid angel seen by Arapuca



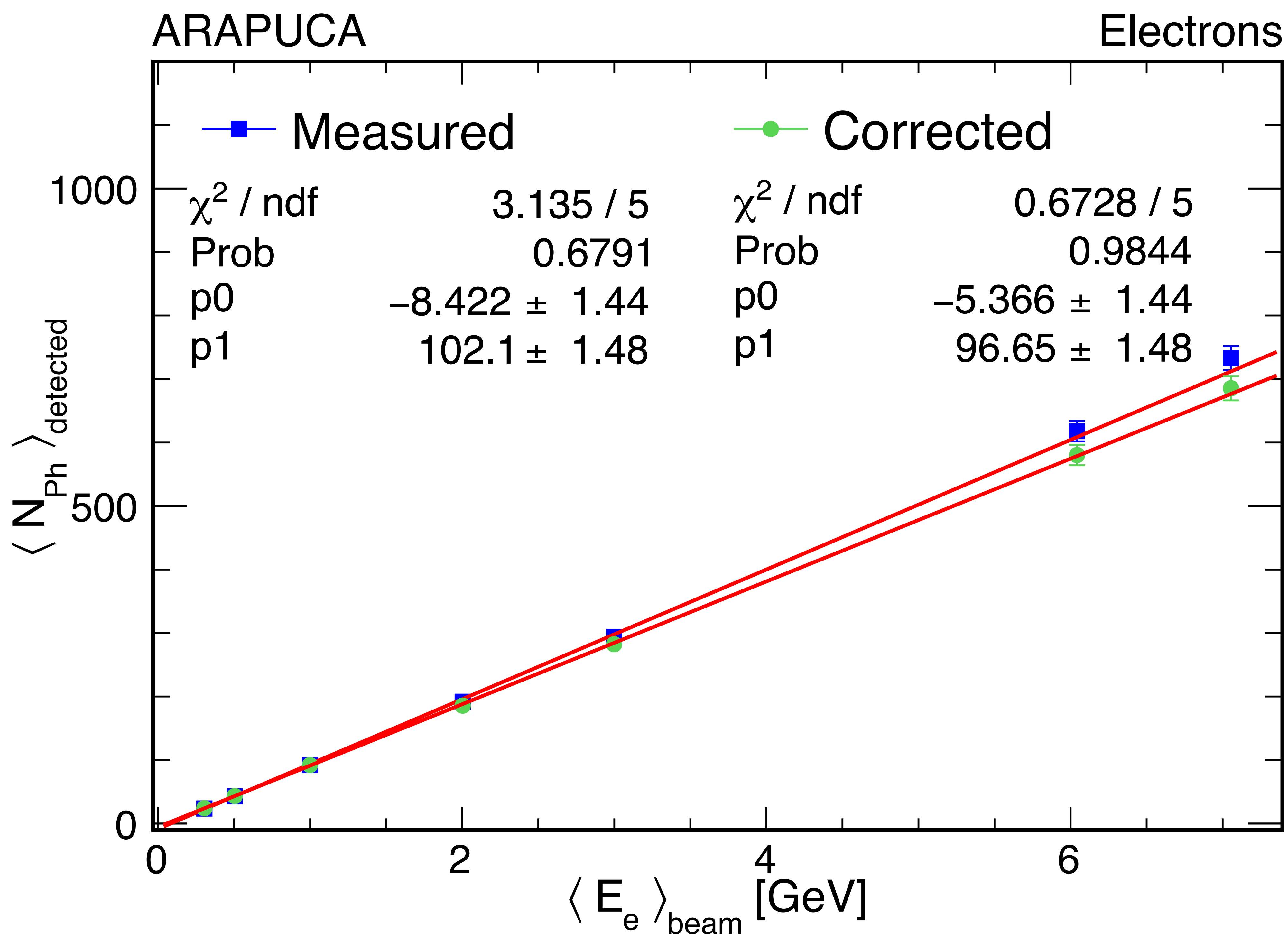




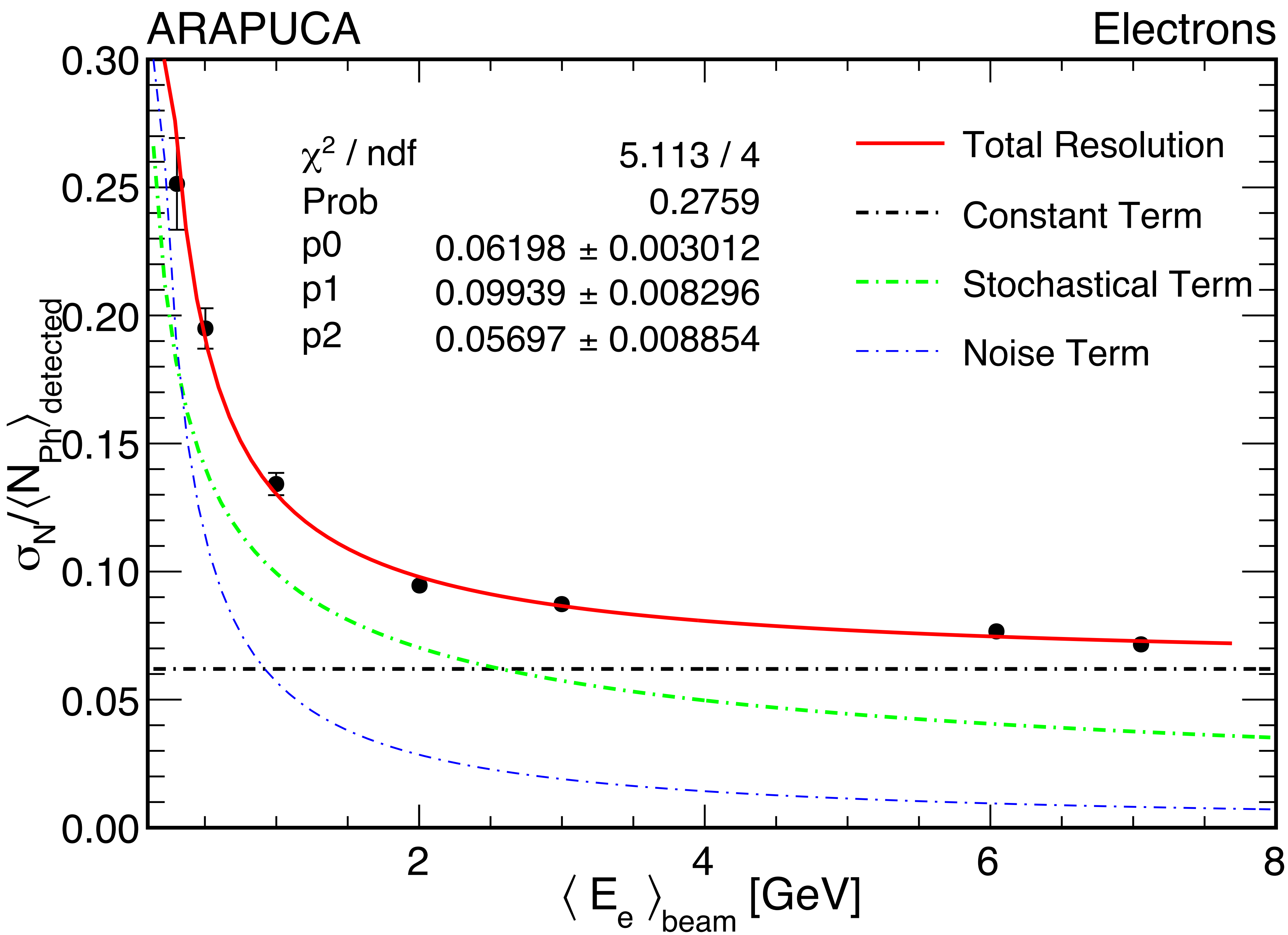
Even if it is small, a dependence of Shower length vs Energy is observed. To increase the linearly accuracy corrections are applied to normalize the light source solid angle seen by Arapuca

Linearity before and after geometrical corrections.

The light yield results smaller, it is expected since the normalization has been chosen to the 1 GeV geometry. Since the beam is not parallel to the Arapuca detector, at higher energies (longer shower) the ionized region is slightly closer to the Arapuca.

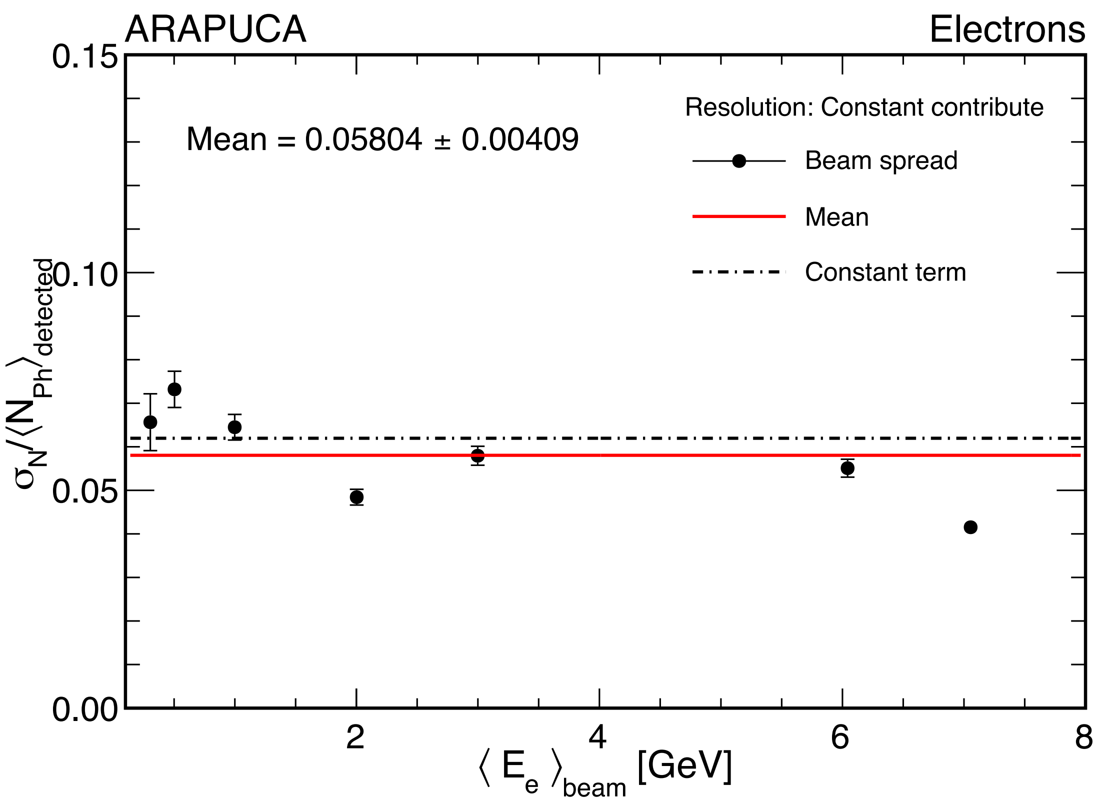


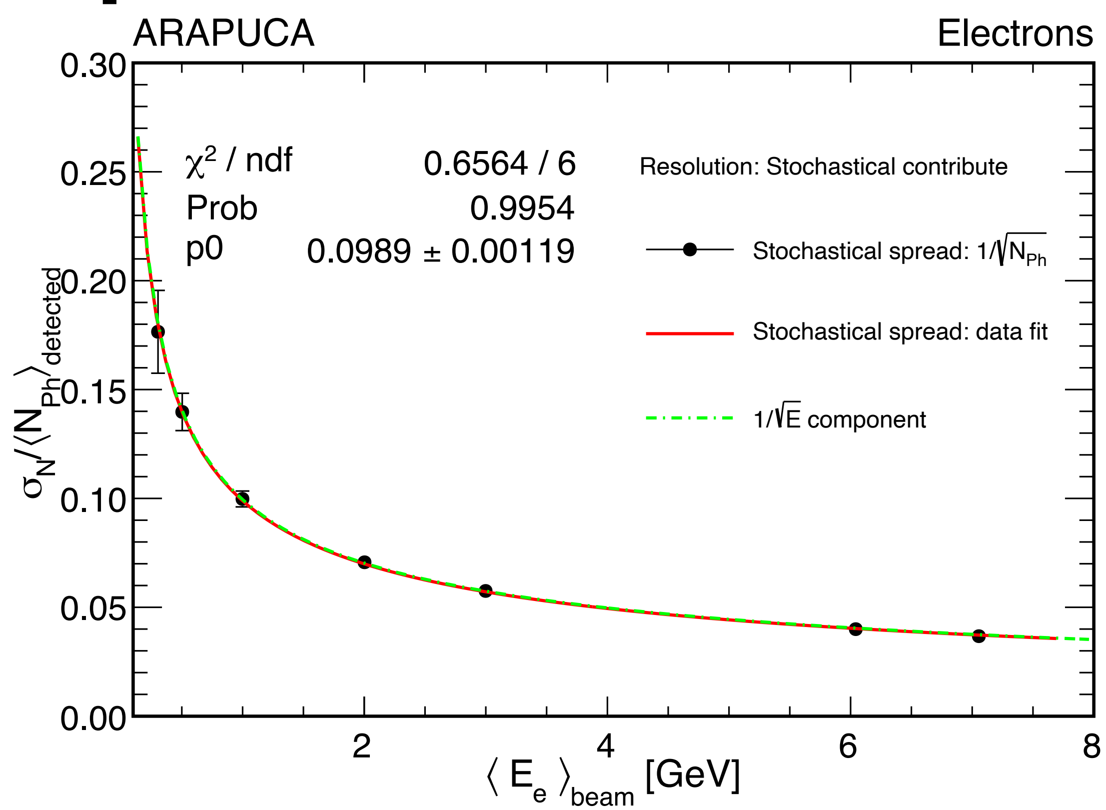
Resolution

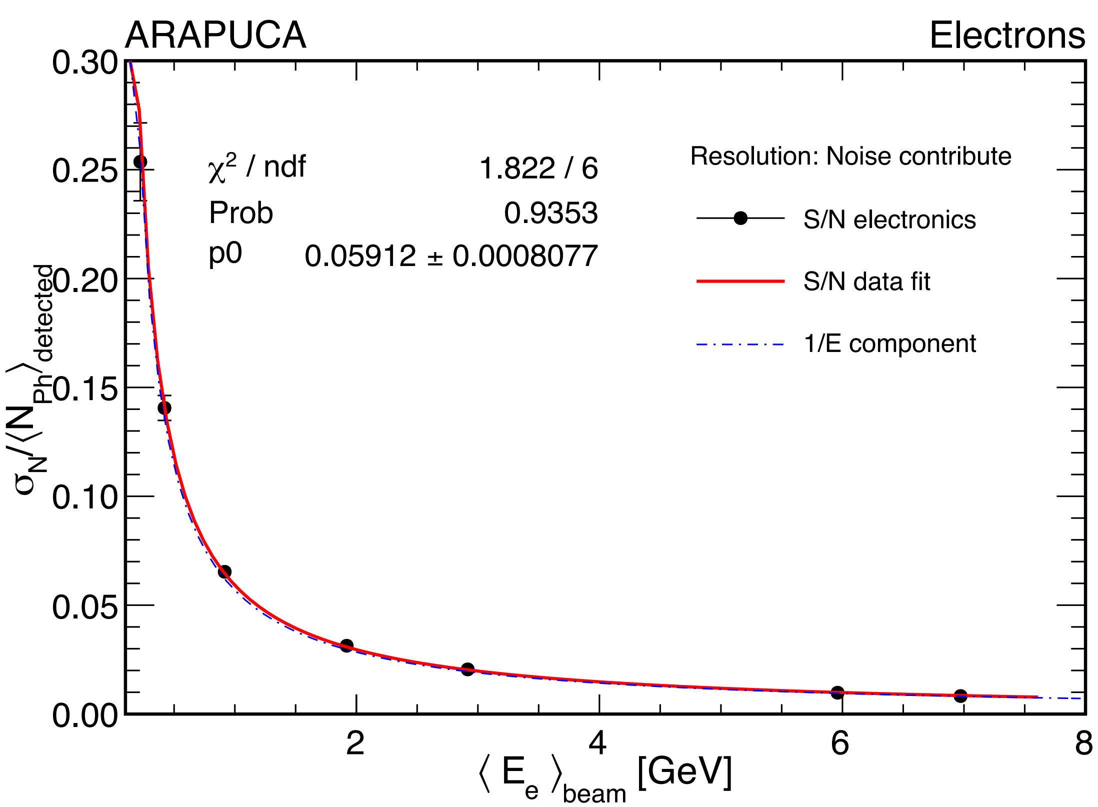


ARAPUCA
Electrons
χ^2 / ndf 5.113 / 4
Prob 0.2759
p0 0.06198 ± 0.003012
p1 0.09939 ± 0.008296
p2 0.05697 ± 0.008854
Total Resolution
Constant Term
Stochastical Term
Noise Term
$\sigma_N / \langle N_{Ph} \rangle_{detected}$
$\langle E_e \rangle_{beam}$ [GeV]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
2
4
6
8

Resolution components







Probably the term 1/E interpretation is not complete.
A source of spread energy independent should come from the energy loss before particles enter the TPC.

Since both Light and Charge show similar value, it can not be associated to the electronic noise (PD ~ same order but TPC <<).

However the 56 MeV values obtained from the Light is a bit overestimated respect the expected one.
Work in progress to review the electronic noise calculation for Arapuca PDM (it was overestimated too).
Considering that electronic noise and energy loss spread have to summed in quadrature can bring to a value compatible with the 56 MeV measured.

Thank you